Effect of hydrostatic pressure on the ambient pressure superconductor $CePt_3Si$

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Abstract

We studied the evolution of superconductivity (sc) and antiferromagnetism (afm) in the heavy fermion compound $CePt_3Si$ with hydrostatic pressure. We present a pressure-temperature phase diagram established by electrical transport measurements. Pressure shifts the superconducting transition temperature, T_c, to lower temperatures. Antiferromagnetism is suppressed at a critical pressure $P_c \approx 0.5$ GPa.

Key words: $CePt_3Si$, superconductivity, antiferromagnetism, hydrostatic pressure

Superconductivity (sc) is one of the most striking effects in solid state physics. In a conventional superconductor Cooper pairing is mediated by phonons. In general, magnetism destroys superconductivity. In heavy fermion systems, however, sc exists in close proximity to magnetism, promoting the suspicion that the sc is mediated by magnetic excitations. Since the discovery of sc in the heavy fermion compound $CeCu_2Si_2$ at atmospheric pressure [1], only a few Ce-based systems were found which also exhibit sc at atmospheric pressure, like $CeMIn_5$ (M=Co, Ir) [4]. Most superconducting pure Ce-based systems show sc only under applied pressure sufficient to suppress long range magnetic order, like $CeIn_3$ [2] or $CeRh_2Si_2$ [3]. $CeIn_3$ displays a typical temperature-pressure phase diagram for these compounds; antiferromagnetism (afm) is suppressed to zero temperature with pressure and sc develops right in the vicinity where afm disappears [2]. Very recently another material, namely $CePt_3Si$, was found showing magnetic order and sc at atmospheric pressure [5]. In contrast to the systems mentioned before, the crystal structure of $CePt_3Si$ is non-centrosymmetric, which is believed to allow for novel superconducting order parameter states. In this work we investigate the pressure dependence of the superconducting transition temperature, T_c, and of the Néel temperature, T_N, by electrical resistivity, ρ, measurements to study the interplay of magnetism and sc in $CePt_3Si$.

Polycrystalline $CePt_3Si$ was prepared by high frequency melting, followed by a heat treatment at 870°C for 10 days. The phase purity was checked by x-ray diffraction and electron microprobe measurements. $CePt_3Si$ crystallizes in a tetragonal structure with no center of inversion symmetry. At ambient pressure $CePt_3Si$ orders antiferromagnetically at $T_N = 2.2$ K and sc develops out of the antiferromagnetic state bellow $T_c = 0.75$ K [5]. At higher temperatures, the resistivity shows two pronounced curvatures at 75 K and 15 K [5]. These features seem to be related to crystal electric field effects in the presence of Kondo-type interactions.

The sample was mounted in a clamp-type pressure cell with a 1:1 mixture of n-pentane and 2-methylbutane as pressure medium. The measured pressure shift of the superconducting transition temperature of tin served as pressure gauge. A standard 4-point Lock-In technique was used to measure the electrical resis-

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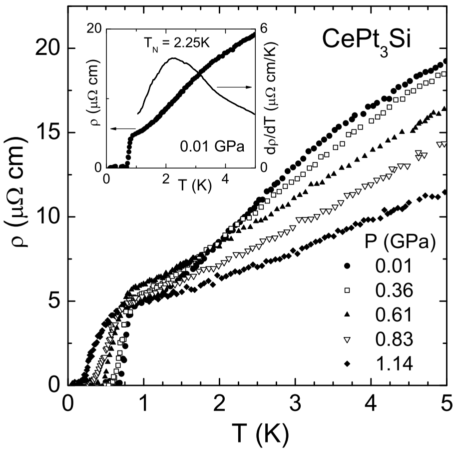

Fig. 1. Resistivity of $CePt_3Si$ as a function of temperature for different pressures. T_c decreases with increasing pressure accompanied by a broadening of the transition. Inset: resistivity and its derivative for the initial pressure $P = 0.01$ GPa. The maximum of the derivative indicates T_N.

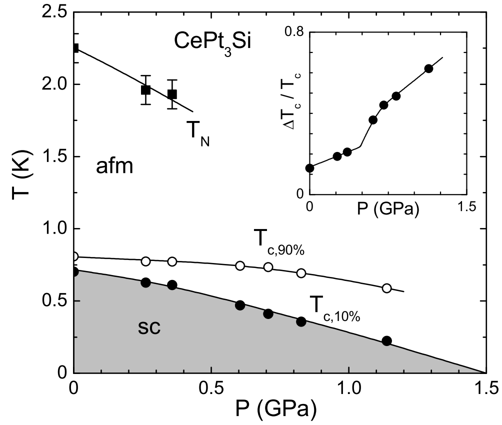

Fig. 2. Onset of the superconducting transition, $T_{c,90\%}$, defined by the temperature where ρ is 90% of the normal state resistivity (open circles), $T_{c,10\%}$ (closed circles) and Néel temperature T_N (solid squares). Inset: relative width of the superconducting transition $\Delta T_c/T_c$. The lines are to guide the eye.

tance.

The antiferromagnetic transition at 2.2 K leads to a change in slope of the resistivity data, shown in figure 1. The well defined maximum in $d\rho/dT$ at T_N is used to follow the pressure dependence of T_N. Up to $P = 0.36$ GPa T_N changes little with pressure, from $T_N = 2.2$ K at ambient pressure to $T_N = 1.9$ K at $P = 0.36$ GPa. The data at $P = 0.61$ GPa show no indication of a magnetic transition anymore. A linear extrapolation of $T_N \to 0$ using the initial slope of $T_N(P)$, $dT_N(P)/dP = (-0.9 \pm 0.2)$ K/GPa, leads to a critical pressure of $P_c \approx 2.4$ GPa. Instead, afm is suppressed at much lower pressure, $P_c \approx 0.5$ GPa, i.e., T_N vanishes non-monotonically in a first order-like transition.

In the paramagnetic phase at temperatures right above T_N at atmospheric pressure, the resistivity decreases with increasing pressure, which can be attributed to an increase of the Kondo temperature T_K. At temperatures bellow T_N at ambient pressure, but above T_c, the behavior of $\rho(P, T{=}\,\text{constant})$ is more complicated. In this temperature range, an increased scattering due to the shift of the magnetically ordered phase to lower temperatures and the decrease due to the shift of T_K to higher temperatures compete. First, with suppressing T_N the resistivity above T_c is increasing, but for pressures above $P = 0.61$ GPa, $\rho(P, T{=}\,\text{constant})$ is decreasing again showing the same behavior like at higher temperatures. This supports our conclusion that magnetism is vanishing in the vicinity of $P_c \approx 0.5$ GPa.

Superconductivity is persisting in a much broader pressure range than antiferromagnetism in $CePt_3Si$. The initial slope $dT_c/dP = -0.18 \pm 0.03$ K/GPa of $T_c(P)$ is quite small. A smooth extrapolation of T_c to higher pressures gives $P^* \approx 1.5$ GPa for the suppression of sc, as shown in figure 2. Corroborated with results from doping studies, where Si is replaced isoelectronically by Ge, corresponding to a negative chemical pressure [6], this indicates that $CePt_3Si$ is close to its maximum T_c already at ambient pressure. This is different from what is observed experimentally in, e.g., $CeCu_2Si_2$ [7] or what is expected from models of spin-fluctuation mediated sc, where T_c becomes a maximum (or minimum) at P_c. Even though no discontinuity can be resolved at P_c a kink in the relative width of the transition $\Delta T_c/T_c$ is observed at about P_c (inset of fig. 2). Since the width of the superconducting transition of tin shows no broadening, this kink seems to be intrinsic to $CePt_3Si$ and not caused by pressure inhomogeneities.

We showed that with increasing pressure afm in $CePt_3Si$ is suppressed non-monotonically in a first order-like transition at $P_c \approx 0.5$ GPa. Superconductivity is not very sensitive to pressure and is persisting in a broad pressure range up to $P^* = 1.5$ GPa. No discontinuity of $T_c(P)$ is observed at P_c. The maximum in $T_c(P)$ seems to be not related to P_c. However, the superconducting transition width $\Delta T_c/T_c$ shows a kink-like feature close to P_c.

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